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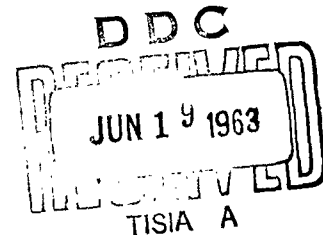
CAMERON STATION, ALEXANDRIA, VIRGINIA

Final Report

December 1, 1960 - November 30, 1962

PROPERTIES OF ATOMIC IONS

Columbia University
Department of Physics
Columbia Radiation Laboratory
New York 27, New York

Contract No. AF49(638)-996

Air Force Office of Scientific Research
Office of Aerospace Research
Washington 25, D. C.

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Optical Detection of Level Crossings in the $(5s5p)^3P_1$ State of Cadmium; P. Thaddeus and R. Novick, Phys. Rev. __126__, [1] 1774 (1962).

Second Order Hyperfine and Zeeman Corrections for an S1 Configuration; A. Lurio, M. Mandel and R. Novick, Phys. Rev. __126__, 1758 (1962).

Abstracts:

Optical Detection of Level Crossings in Zn^{67}; A. Landman, P. Thaddeus and R. Novick, Bull. Amer. Phys. Soc. II, __7__, 27 (1962).

An Intense Source of Monoenergetic Metastable Helium Ions; M. Lipeles, L. Gampel and R. Novick, Bull. Amer. Phys. Soc. II, __7__, 69 (1962).

Lifetime of the Metastable Helium Ion; E. Commins, L. Gampel, M. Lipeles, R. Novick and S. Schultz, Bull. Amer. Phys. Soc. II, __7__, 258 (1962).

Lifetime of the $(5s5p)\,^1P_1$ State of Cd and Coherence Narrowing of the 2288 Å $(^1S_0-^1P_1)$ Level-Crossing Resonance Signal; A. Lurio, R. Novick and P. Horwitz, Bull. Amer. Phys. Soc. II, $\underline{7}$, 258 (1962).

Hfs of the $^1P_1$ State of Cd^{111}; R. Novick and A. Lurio, Bull. Amer. Phys. Soc. II, $\underline{7}$, 258 (1962).

Detection of Level Crossings in Backscattering; R. Goshen, A. Landman and R. Novick, Bull. Amer. Phys. Soc. II, $\underline{7}$, 433 (1962).

Papers Presented at Meetings:

International Conference on Optical Pumping, University of Heidelberg, Germany, April 26-28, 1962:

Lifetime of the Metastable Helium Ion; E. Commins, R. Novick, L. Gampel, M. Lipeles and S. Schultz.

Lifetime, Coherence Narrowing and Hfs of the $^1P_1$ State of Cd as Determined by the Level Crossing Technique; A. Lurio and R. Novick.

Sixth Brookhaven Conference of Molecular Beams, Brookhaven National Laboratory, N.Y., June 11-13, 1962:

A Search for the Metastable $(1s2s2p)\,^4P_{5/2}$ Li Atom; L.Y. Chow Chiu, P. Feldman and R. Novick.

Lifetime of the Metastable Helium Ion; E. Commins, L. Gampel, R. Novick, M. Lipeles and S. Schultz.

Level Crossing Spectroscopy; R. Novick.

Final Report

Contract AF 49(638)-996

Introduction

This is the final report of work on the properties of atomic ions supported by the Air Force Office of Scientific Research under Contract AF 49(638)-996 during the period December 1, 1960 through November 30, 1962.

The work supported by this contract can be divided into four categories: 1. The lifetime of the metastable helium ion; 2. Level crossing spectroscopy; 3. Atomic lifetimes; and 4. A study of the metastable lithium atom. The first item was discussed in the contract proposal and the others were proposed to the contracting officer and were discussed in subsequent proposals. The status of each of these areas of research is presented in detail in the remainder of this report.

The helium lifetime work has progressed satisfactorily; there are, however, some outstanding problems that are being actively investigated. We have obtained a preliminary value for the lifetime and we are now engaged in a study of some beam trajectory problems. Preliminary reports on this work have been made at the Spring 1962 Meeting of the APS, at Brookhaven and at Heidelberg.

The level crossing work has produced a number of new results. In particular we have obtained precise values for the atomic magnetic moment of the $(5s5p)^3P_1$ state of cadmium and the $(4s4p)^3P_1$ state of zinc. The cadmium work has been described in Phys. Rev. 126, 1774 (1962), and the zinc work is described below. In addition, we have published an article (Phys. Rev. 126, 1758 (1962)) on the theory of second order hyperfine and Zeeman interactions. A full understanding of these effects is necessary for an accurate interpretation of our results. A number of abstracts have also been published.

The atomic lifetime work is adequately described below. This work has been undertaken partly for its intrinsic interest and partly as a preliminary to the study of the spins and moments of the radioactive isotopes of Ca, Sr, and Ba. These elements are highly reactive and we must develop a number of new techniques for producing light sources and scattering cells.

The work on lithium has been most exciting and has led to the discovery of a new metastable state (see below). This state has some unusual properties that may make it useful for the production of polarized ions and electrons. This metastable state has a lifetime of about 10 μsec and decays with

the emission of an electron (autoionization). If we can polarize this state before it decays, the outgoing electron and ion will be polarized and can be injected into a suitable accelerator. This may provide a cleaner source of polarized electrons and ions than has been available heretofore.

I. Lifetime of the Metastable State of 2S He$^+$

This is an experiment to measure the lifetime of the

2S state of singly ionized helium. During the first year

of support under this contract, an atomic beam apparatus

was constructed and a rough measurement made. During the

past year, this apparatus has been improved so that we

will be able to measure the lifetime with greater precision.

This work is continuing.

Breit and Teller[1] have shown theoretically that two-

photon decay is the dominant process in the decay of the 2S

state in hydrogen atoms where the normal single quantum

electric dipole transition is forbidden by the parity

selection rules. Higher order single photon processes are

strongly forbidden. The latest theoretical values[2] for

the lifetimes of the 2S states in hydrogen and singly

ionized helium are respectively 0.12 sec and 1.9 millisec.

An experimental measurement of this lifetime would provide

a test of the two-photon decay process for a precisely

calculable case. A precise determination of this lifetime

would also be a sensitive independent test of the vanishing

of the electric dipole moment of the electron[3] which, if

it existed, would mix the 2S and 2P states, thus shortening

the lifetime of the 2S state.[4] The vanishing of this

moment is implied by time reversal invariance and conser-
vation of parity in electromagnetic interactions. The
lifetime would also be shortened by the existence for the
electron of a parity non-conserving point contact (anapole)
interaction.[5]

The only previous direct work on the lifetime of
this state was that of Fite and coworkers[6] in hydrogen.
They set a lower limit on the lifetime which is about 50
times smaller than the predicted value. The difficulties
of working with such a long lifetime in neutral hydrogen
prevented a better measurement. However, in the case of
the helium ion, the lifetime is much shorter and the charge
allows magnetic collimation of a beam. Nevertheless, there
are still stringent conditions to be met. In the measuring
region, electric fields must be kept below a few tenths of
a volt per centimeter, magnetic fields must be kept down to
the order of 50 gauss and the background pressure must be
less than 1×10^{-8} torr. If these conditions are not
satisfied, Stark and collision quenching will be competing
decay processes, both greater than 1 o/o of the two photon
process.

The plan of our experiment is to measure the lifetime
of the 2S state of singly ionized helium by time of flight.

We have chosen a thirty-foot flight path which is one quarter of a decay length for a 10 ev metastable helium ion. The ions are collimated in this path by an axial magnetic field of about 50 gauss. Electron bombardment produces ions of which about 1 o/o are in the 2S state. This 2S component is modulated by passing the beam through a microwave cavity in which power at the Lamb shift frequency (14 kMc) is turned on and off at 280 cycles. Transitions to the short lived $2P_{1/2}$ states are induced by this microwave field. The modulated beam is then focussed by a series of electrostatic lenses through a series of pressure separation holes into the thirty-foot drift chamber. Here the beam impinges on a flat movable detector. Since the Auger ejection of electrons by ground state and metastable ions is different, the modulated metastable beam gives rise to an ac signal at this detector. From the decrease of this ac signal relative to the dc signal as a function of distance the lifetime of the state will be determined.

At the beginning of the period of this contract the thirty-foot vacuum chamber had been built and was being vacuum tested especially with respect to gasket design and gasket material. Development of an ion source had

reached the stage of a second model, and experiments had to be performed on methods of pressure separation of the source from the drift chamber.

The main vacuum chamber consists of six five-foot, eight-inch diameter stainless steel sections. They are wound with an open helix of half-inch copper tubing which provides the axial collimating field of 50 gauss for a current of approximately 120 amperes. The pump on this chamber is a PMC 721 oil diffusion pump baffled by an aluminum water baffle and a stainless steel liquid nitrogen baffle with a copper chevron insert. The proposed copper gaskets which had actually been used previously in this laboratory had a double knife edge within the bolt circle and provision for pumping on the trapped space. It soon became obvious that a support was needed outside the bolt circle for flanges between two sections, and we converted to a double knife edge straddling the bolt circle. The gasket material was changed to aluminum which, despite more difficult sealing and differential expansion, proved successful in solving the serious problem of oxidation of the inner knife edge during baking. Ten feet of the apparatus were in fact baked and pumped down to 2×10^{-9} torr.

The other, more crucial problem was that of developing an intense, clean beam of metastable ions. This is intimately connected with the method of pressure separation since the beam must be focussed through the separation openings. The original plan called for a source chamber and an intermediate chamber separated from each other and the drift chamber by 1/2 inch diameter tubes about one foot long. These, in fact, provide a pressure differential of about 100 each, which would contribute a partial pressure of 10^{-9} torr for a source pressure of 10^{-5} torr while at the same time allowing for valves to separate the chambers for testing. This has the seemingly modest requirement of collimating an ion beam to a diameter of one-half inch over the length of about three feet. A simple cylindrical source had been constructed to produce a beam of about this size in a magnetic field. However, the uncertainty in launching the beam precluded keeping it collimated by a magnetic field of 50 gauss, since an ion travelled about 3 feet during one cyclotron period in this field. A more compact source with a linear electron beam was then constructed and thoughts were turned to changing the pressure separation to small apertures. The source provided an intense beam (5×10^{-8} amp)

with only a 5/32 inch aperture, but it was observed, as
with the first source, that with the magnetic field on,
electrons were present in the beam. These results led
to two major fruitful changes in the apparatus. The
5/32 inch beam from a bakeable, cleaner version of the
new source was now focussed by means of a hemispherical
Pierce type [7] of lens to a 0.090 inch diameter beam. A
new combined source intermediate chamber with a separat-
ing hole of 0.090 inch diameter by 1 cm long was built.
Under this arrangement [8] a 5×10^{-8} amp beam of helium
ions at 10 ev was produced with a pressure separation of
about 35 to 1. This beam, of which about 1 o/o was in
the 2S state, had a kinetic energy spread of less than
1 ev.

Now the problem remained to further reduce the back-
ground helium pressure without losing substantial amounts
of the beam. The new chamber included a three cylinder
electrostatic lens. A study of the focussing properties
of this lens led to a 0.110 inch diameter separating hole
leading to the next chamber. However, the pressure
separation was not that expected by almost a factor of 10.
This was attributed to poor pumping out of the lens area.
Later this was alleviated by using mesh rather than solid

surfaces for the lenses and by the addition of a second

separation chamber. At the entrance to the drift tube

a final electrostatic lens focussed the beam down the

tube. Severe beam scalloping was observed with this

setup. However, by refocussing for each detector, meta-

stables were seen over the full length of the apparatus.

The apparent decay of metastables for the 400μ second

transit time was 20 o/o, which is consistent with the

1.9 millisec theoretical value.[9] Although no actual

numerical value can be stated with reasonable certainty,

this measurement is a considerable improvement over that

of Fite.[6]

Several major improvements were next made on the

apparatus. First, the above-mentioned mesh lenses and

additional separating chamber were constructed. Second,

to eliminate contamination of the ion source and lenses

by oil deposits, the oil diffusion pumps were replaced

with mercury diffusion pumps of equivalent speed and new

creep-free liquid nitrogen baffles with 24 hour holding

time were constructed. There were also problems with

the magnetic field collimation. One was that operating

the source and lenses in a field gave rise to some

electron contamination and difficult focussing. The

second was the previously mentioned beam scalloping.

Fortunately, we were able to solve both problems with
only one change. To prevent, or at least minimize,
beam scalloping, we hoped to achieve conditions near to
those for Brillouin flow, which occurs when the space
charge forces just balance the radial magnetic field
forces and the beam forms a stable cylinder. This is
best achieved by abruptly introducing the beam into the
magnetic field. Thus, a large Armco plate was included
as the last flange on the new intermediate chamber.
This served to eliminate the magnetic fields in the
source and lens regions. With the new system operating,
the flow of helium into the drift chamber was 5.5×10^{-7}
atm cc/sec for a source chamber pressure of 2.0×10^{-5}
torr (air equivalent), which gave -- assuming a pumping
speed of 50 liter/sec -- a contribution of only 8×10^{-9}
torr of helium pressure. We also obtained an ion beam
of 5×10^{-9} amperes over the entire length of the
apparatus with considerably less scalloping than before.
We are studying the scalloping, or lack thereof, under
various conditions, and also the ratio of metastable to
ground state ions under various conditions. This should
lead to a definite measurement of the lifetime in the
near future. Present stability of beam under certain
conditions also indicates that a good precision may be

obtainable in this determination. This work is being actively pursued.

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(2) L. Spitzer and J. Greenstein, Astrophys. J. 114, 407 (1951); J. Shapiro and G. Breit, Phys. Rev. 113, 179 (1959).

(3) D. F. Nelson, A. A. Scupp, R. W. Pidd, and H. R. Crane, Phys. Rev. Letters 2, 492 (1959).

(4) E. E. Salpeter, Phys. Rev. 112, 1642 (1958); G. Feinberg, Phys. Rev. 112, 1637 (1958).

(5) G. Feinberg, private communications; Ia.B. Zel'dovich, Soviet Physics JETP 6, 1185 (1958).

(6) W. L. Fite, R. T. Brackman, D. G. Hummer, and R. F. Stebbings, Phys. Rev. 116, 363 (1959).

(7) J. R. Pierce, Theory and Design of Electron Beams (D. Van Nostrand Company, Inc., Princeton, N. J., 1954).

(8) M. Lipeles, L. Gampel, and R. Novick, Bull. Amer. Phys. Soc. II, 7, 69 (1962).

(9) E. Commins, L. Gampel, M. Lipeles, R. Novick, and S. Schultz, Bull. Amer. Phys. Soc. II, 7, 258 (1962).

II. Level Crossing Experiments in Zinc

Optical detection of level crossings in the $(4s4p)^3P_1$ state of the stable isotope Zn^{67} and of the radioactive isotope 245 day Zn^{65} has resulted in a determination of the hyperfine coupling constants in the two isotopes as well as a new, precise value for the atomic moment (g_J). Another set of experiments has led to a value for the lifetime of the $(4s4p)^1P_1$ state of zinc. These latter experiments were performed using naturally occurring zinc (96 o/o even isotopes), and included the observation of coherence narrowing.

In the experimental setup for the triplet state experiments, an electrodeless rf discharge lamp was used to produce light which was transmitted through a set of 4" quartz lenses and impinged on a scattering cell. Two types of scattering cells were used, one spherical and the other cylindrical (with typical dimensions of one inch). These scattering cells were contained in an oven which was heated by a gas-oxygen flame. The scattering cell was placed at the center of a 12" Harvey-Wells magnet, having a homogeneity of about 1 part in 10^5 over the cell region. The magnetic field was applied perpendicular to the direction of the incoming and scattered light, which was gathered into a light pipe perpendicular to the incoming light. At the end

of the light pipe, a Schott UG-11 filter passed the light at 3076 Å into a photomultiplier tube and associated circuits; from there the signal went to a phase-sensitive, lock-in detector, and finally to a recorder. The steady field at which crossing occurred was modulated by a small magnetic field at 30 cps, and the observed signal was the derivative of the Lorentzian curve to be expected from the theory, i.e., a dispersion-type curve.

In the case of Zn^{67}, all four crossings for which the two degenerate levels differ in m_F by 2 were observed. The magentic field values at which crossings were observed to occur, measured in units of the nuclear magnetic resonance frequency of protons in mineral oil, together with the low field assignment of the levels, are:

(F,m_F) = (7/2,-7/2) and (5/2,-3/2) at 3702.755 $\pm$ .020 kc/sec;

(5/2, 1/2) and (5/2,-3/2) at 3807.79 $\pm$ 0.20 kc/sec;

(5/2, 3/2) and (5/2,-1/2) at 3922.95 $\pm$ 0.30 kc/sec;

and   (5/2, 5/2) and (5/2, 1/2) at 4094.4 $\pm$ 0.6 kc/sec.

The crossings were progressively weaker and broader. A more precise determination of the hyperfine coupling constants than has heretofore been possible may be achieved once a mathematical analysis of all four crossings has been completed. Corrections due to the nearby $^3P_2$ and $^3P_0$ states result in very complicated mathematical expressions involving the explicit solution of third degree equations, except in the

case of the major crossing, i.e., the first one listed above.
The other three so-called fold-over crossings may be very
sensitive to corrections because of the relatively slow
change in energy of the states involved in the magnetic
field. This possibility is being examined.

The hyperfine constants for Zn^{67} are:

$$A_{uncorrected} = 608.99 \pm 0.02 \text{ Mc/sec},$$

$$B_{uncorrected} = -19.76 \pm 0.10 \text{ Mc/sec},$$

with

$$g_J = 1.500097 \pm 0.00006.$$

In the case of Zn^{65}, three crossings for which the two
degenerate levels differ in m_F by 2 were observed. A number
of lamps, including the flow type lamp, were tried. Best
results were achieved with the lamp which was used in the
double resonance experiment on Zn^{65}. The radioactive scat-
tering cell was also the same one used in the double
resonance experiment.

The magnetic field values at which crossings were
observed, measured in units of the nuclear magnetic resonance
frequency of protons in mineral oil, together with the low
field assignment of the levels are:

$(F,m_F) = (7/2,-7/2)$ and $(5/2,-3/2)$ at $3253.52 \pm .06$ kc/sec;

$(5/2, 1/2)$ and $(5/2,-3/2)$ at $3238.00 \pm .30$ kc/sec;

$(5/2, 3/2)$ and $(5/2,-1/2)$ at $3221.90 \pm .40$ kc/sec.

These values, together with the value for g_J obtained from the experiments on Zn^{67}, can be used to obtain un-corrected values for A and B, which are as follows:

$$A_{uncorrected} = 535.08 \pm .03 \text{ Mc/sec,}$$

$$B_{uncorrected} = 2.10 \pm .15 \text{ Mc/sec.}$$

With the inclusion of approximate second-order corrections, as obtained from the Zn^{67} double resonance experiment, a very good set of corrected values can be obtained for A and B. Since the dipole moment of Zn^{65} is .88 that of Zn^{67}, and since the corrections for Zn^{67} are .14 Mc/sec and 1.00 Mc/sec, respectively, for A and B, we obtain

$$A_{corrected} = 535.08 + .88 \times .14 \pm .03 \text{ Mc/sec}$$

and $$B_{corrected} = 2.10 + .88 \times 1.00 \pm .15 \text{ Mc/sec.}$$

These values,

$$A = 535.20 \pm .03 \text{ Mc/sec}$$

and $$B = 2.98 \pm .15 \text{ Mc/sec,}$$

are in complete agreement with the double resonance experiments performed in this laboratory on Zn^{65}.

The last set of experiments to be described involve the lifetime and coherence narrowing of the $(4s4p)^1P_1$ state of Zn. The zero magnetic field level crossing (Hanle effect) was studied in detail. Ordinary zinc, consisting of 96 o/o even isotopes, was enclosed in a quartz cell and irradiated with 2138 Å resonance radiation from a flow-type lamp. The

intensity of the fluorescence emitted at 90° was observed
as a function of the cell temperature and magnetic field,
and a Lorentzian level crossing signal was observed at
zero field. Using modulation and phase sensitive detection,
the derivative of the signal was traced out on a recorder
chart. The field width of the crossing signal decreased
as the zinc vapor density, corresponding to the cell
temperature, was increased. This narrowing, which is
attributed to coherence, is in excellent agreement with
theory. A plot of the effective lifetime as a function of
zinc vapor density is given in the accompanying figure. The
lifetime of the $^1P_1$ state is determined to be 1.36 ± 0.10
x 10^{-9} sec by extrapolating the width of the crossing
signal to zero zinc density. This value is significantly
lower than values quoted before this study was made.

MEASURED LIFETIME OF $^1P_1$ STATE OF ZINC VS DENSITY
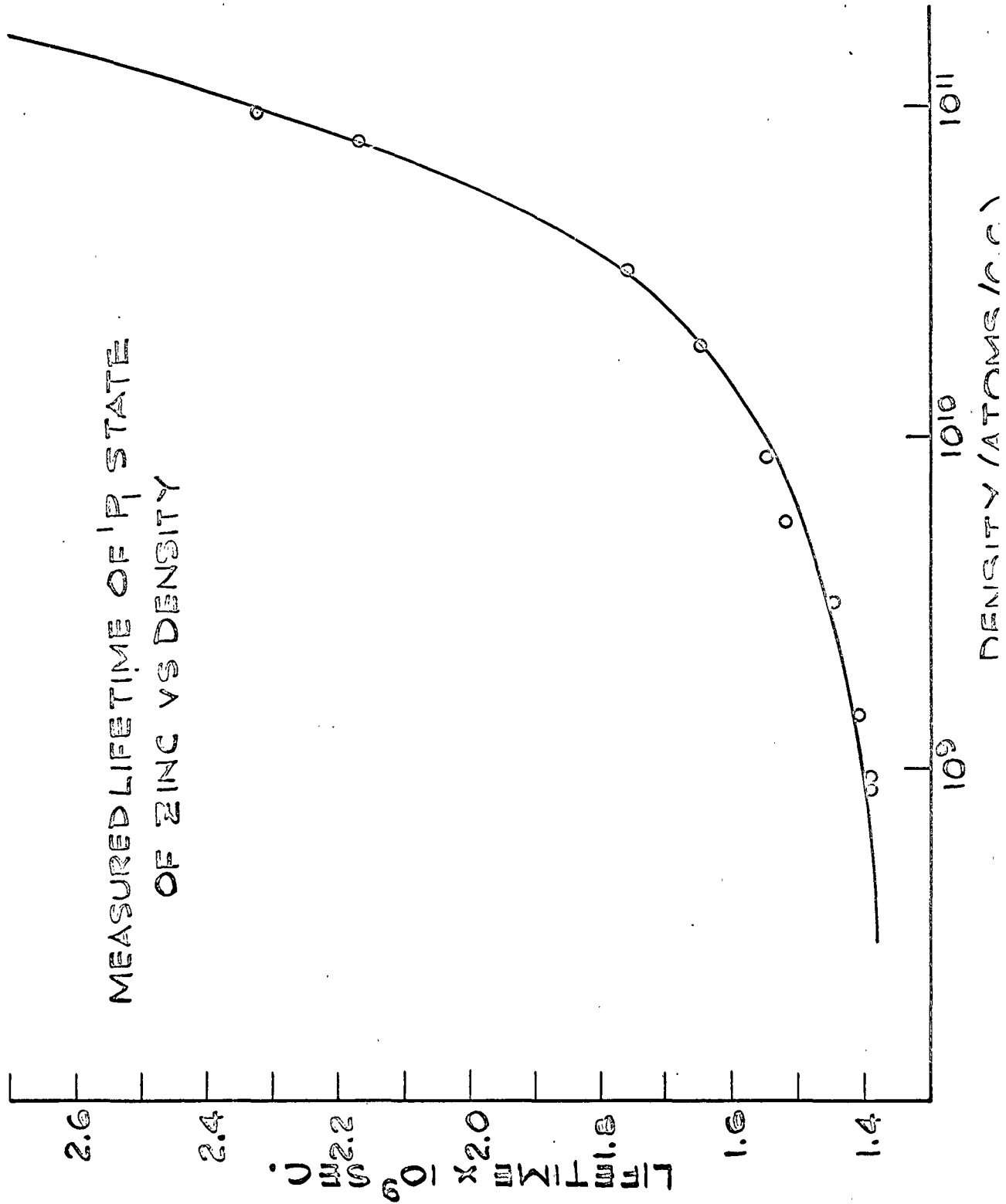
III. <u>Lifetimes of the</u> $^1P_1$ <u>States of Ca, Sr and Zn</u>

During the past year we have undertaken the measurement
of the first excited state lifetimes of three elements in
the Group II series of the periodic table. Calcium,
strontium, and zinc have been studied by means of the so-
called Hanle effect on an atomic beam of the elements in
question. The motivation for these experiments was twofold:
a) Very few atomic excited-state lifetimes are known
within a factor of 2 or 3 at best; even experiments which
claim high accuracy often disagree with one another by
considerably more than the assigned limits of error. On
the other hand, accurate lifetime values, or equivalently,
accurate oscillator strengths and spontaneous transition
probabilities are of interest for a number of purposes,
particularly in astrophysical applications. b) The present
work in zinc complements other lifetime measurements made
in this laboratory during the past year on zinc and
cadmium, again using the Hanle method, but in an atomic
vapor in a sealed cell. The latter measurements were
undertaken to explore coherence narrowing effects in
optical pumping as a function of atomic vapor pressure,
and the atomic beam measurement in zinc was made as a
check on the validity of the low-pressure extrapolation
for the sealed-cell data.

We employ an atomic beams apparatus with optical excitation and detection systems. The source oven contains Sr, Ca or Zn in natural abundance. The scattering chamber is equipped with Helmholtz coils for producing a dc field and a modulation pair for phase sensitive detection of signal. A flow type lamp provides an intense, non-self reversed beam of resonance radiation. The flow of argon keeps the alkaline earth metal from either plating out on the wondow or attacking the hot quartz and also greatly reduces loss of intensity through self reversal. The vapor pressure of the elements and the strength of the radio frequency discharge can be varied independently, allowing us to choose the best operating parameters for the lamp for maximum intensity. The $^1S_0 \longrightarrow {}^1P_1$ resonance photons are linearly polarized and incident along the direction of the field. They are scattered from the beam and observed at right angles to the incident radiation and in the direction of polarization. The signal-to-noise ratio was great enough to allow direct dc photo-detection.

From a classical point of view, the Hanle effect may be thought of as due to the magnetic field-dependent precession of a dipole excited by the linearly polarized incident radiation. With zero magnetic field (and therefore

no dipole precession) no light will be re-radiated along
the direction of the photo-detector. As the magnetic
field increases, the rate of precession increases, and a
greater and greater percentage of the re-radiatid light
reaches the detector. The effect is obviously symmetric
with reversal of the field direction. A detailed calcu-
lation shows that the expected distribution of intensity
as a function of magnetic field strength should be an
inverted Lorentzian curve. The Lorentzian curves thus
obtained are fitted to determine their widths at half
maximum. We have developed a method of reducing the data
so that a straight line could be fitted to the experimental
points, from which, in turn, the pertinent parameters may
be derived. A weighted least-squares fit was made by an
IBM 1620 program to determine the slope and intercept of
the best fit straight lines. From these the width of the
Lorentzian curve, and finally the lifetime, are determined.
Runs are made under widely varying conditions of beam oven
temperature, light intensity, stray magnetic field com-
pensation, and with and without a linear polarizer in the
scattered beam.

Table I shows the results obtained in this series of
experiments as compared with the most recent data by two
Russian investigators using other methods, as well as

Table I

Summary of Experimental Results

	Ca $^1S_0 - {}^1P_1$ τ $(10^{-9}$ sec)	Sr $^1S_0 - {}^1P_1$ τ $(10^{-9}$ sec)	Zn $^1S_0 - {}^1P_1$ τ $(10^{-9}$ sec)
Present work at Columbia	4.69 ± 0.46	4.92 ± 0.27	1.49 ± 0.17
Ostrovskii and Penkin[a]	5.44 ± 0.15	6.25 ± 0.20	
Calculated by Trefftz[b]	5.54		
Calculated by Ushpalis and Chiplis[c]	5.40		
Calculated by Vainshtein[d]	3.48		

[a] Y.I. Ostrovskii and N.P. Penkin, Optics and Spectroscopy (USSR) 11, 307 (Nov. 1961).

[b] E. Trefftz, Z. Astrophys. 28, 67 (1950).

[c] K. Ushpalis and I. Chiplis, Abstracts of reports from 13th All-Union Conference on Spectroscopy Izd. Akad. Nauk SSSR, Moscow-Leningrad, 1960.

[d] L.A. Vainshtein, Opt. i Spektr. 3, 313 (1957).

three theoretical calculations for the case of calcium.

Our data are consistent under a wide variety of experimental conditions. The limit of error quoted here represents about twice the standard deviation in the spread of lifetime values obtained under variation of several parameters, including beam oven temperature, compensating magnetic fields, and placement of a linear polarizer in the scattered beam, as well as different methods of weighting the experimental points during the parametric fitting process. In the case of strontium, however, serious disagreement exists between our work and that of Ostrovskii and Penkin. The latter is based on the so-called "hook method," involving determination of both the anomalous dispersion in the wings of the resonance curve as the light passes through an atomic vapor, and the integrated density of the vapor over the optical path. The method is inherently more complicated than the one we have used. We cannot explain the present discrepancy. We have made no correction for the odd isotope Sr^{87}, present in about 7 o/o abundance in our natural sample (primarily Sr^{88}). This may introduce some complications, but the agreement of results with and without the second linear polarizer in the scattered beam tends to indicate that any corrections would have a small

effect. The effect of this polarizer is to filter out roughly two-thirds of the light re-radiated from the $^1P_1$ state of Sr^{87}. This is the fraction of radiation due to the multiplicity of magnetic substates available in the ground state of this atom. As far as we can determine, no correction in the Russian work has been made for the presence of Sr^{87}, and this may have at least as great an influence on their results as on ours.

The theoretical results presented for calcium are subject to some uncertainty due to their dependence on detailed knowledge of the atomic wave functions. The third calculation, by Vainshstein, is based on a single electron approximation, and is probably somewhat less reliable than the others.

A considerable amount of work remains to be done in this area. A more elaborate apparatus capable of more precise measurements is in the planning stage. It will be able to handle elements whose physical and chemical properties present severe difficulties. The lifetime of the $^1P_1$ excited state of magnesium is currently being studied in the present apparatus.

IV. Metastable Lithium Atom

This section describes the work performed on the metastable $(1s2s2p)^4P_{5/2}$ state of lithium. The purpose of the work has been two-fold: 1) to produce and detect a beam of atoms in this metastable state which, though theoretically predicted, has never been observed because of the short lifetime of the state; and 2) to determine the lifetime and production cross-section of the state, and through fine- and hyperfine-structure measurements, to study the nuclear structure of Li^7. At the present writing, we have succeeded in producing and detecting the metastable atoms and we have begun a study of their properties.

The $(1s2s2p)^4P_{5/2}$ configuration for a three-electron system corresponds to the lowest possible bound state of the negative helium ion. The doublet states $(1s2s2p)$ $^2P_{3/2,1/2}$ autoionize with lifetimes $< 10^{-13}$ sec, and the $^4P_{3/2,1/2}$ states are also short-lived because of mixing with the doublet states. The $^4P_{5/2}$ state alone is metastable against autoionization. The only final state for autoionization consistent with parity and angular momentum conservation is the $(1s1s)^1S_0;(kf)^2F_{5/2}$ configuration of a ground state lithium ion and a free electron, which is connected to the metastable state through the spin-spin

operator between these states has been estimated using product
hydrogenic wave-functions with effective nuclear charges, and
the lifetime has been estimated to be $\sim 1.6 \times 10^{-5}$ seconds.

The energy of the metastable state is ~ 53 eV above the
ionization potential of Li, and lies well below the first
excited states of Li$^+$ ($^3S_1 \sim 63$ eV). The state can be
produced by exchange excitation of neutral lithium atoms by
electron impact, the estimated cross-section for this process
being $\sim 10^{-19}$ cm^2. Two methods of detection are possible.
Originally, we allowed the metastable atoms to impinge upon
a metal plate, and then collected Auger electrons which were
ejected from the metal. However, such a detector is also
sensitive to radiation from the normal excited states of Li
and Li$^+$, and the photoelectron signal is of such magnitude
as to mask the signal due to metastable atoms. The use of
such a detector leads to further complications because the
photoelectron signal is not constant in time, but varies as
the detecting surface changes due to the deposition of
lithium atoms on it.

The second method of detection is to collect the ions
or electrons resulting from the autoionization of the meta-
stable state. In addition to suppressing the photoelectron
background, this detector also identifies the metastable

state by its decay products, and serves to support the
assumed theoretical decay mode. In our experimental runs
we have found the excitation curve to be similar both in
shape and magnitude when we collected, alternatively,
ions or electrons. Although we have not yet made accurate
determinations of the $^4P_{5/2}$ lifetime or cross-section, all
of the data taken to date are consistent with the above
theoretical considerations.

The design criteria for the experimental apparatus
include minimum source-to-detector distance, separation of
source and detector to prevent noise from stray ions or
electrons, clean vacuum for maximum electron gun efficiency,
and high sensitivity detection of charged particles. A
stainless steel vacuum system was constructed employing
Vacion high-vacuum pumps and metal gasketing. The ultimate
pressure after mild bakeout is below 10^{-8} torr. The
system is separated into two chambers connected only by a
narrow slit. The source to detector distance is 3 cm so
that 13 o/o of the metastables produced reach the detector
(the decay length is 1.5 cm). The electron gun is
attached to a molybdenum oven, the axis of the gun being
centered in a strong magnetic field. The bombardment
region itself is a .008" slit attached to the aperture of
the oven, followed by a continuation of the oven canal to

prevent electrons from the gun from entering the detector region. The magnetic field collimates the electrons through the slit and serves to deflect ions and electrons out of the lithium beam. A control grid at the entrance to the detector also helps to prevent charged particles from reaching the detector.

The detector itself is completely enclosed so that only particles that are in the lithium beam can be collected. However, since we use grids and the magnetic field to prevent charged particles from entering the detector, only those charged particles resulting from the decay of neutral metastable atoms should be collected. We cannot prevent photons from entering the detector, but we can choose the detector geometry to minimize photoelectron current due to scattered radiation. Such a detector is presently in use with an electrometer capable of reading currents as low as 10^{-16} amperes. The electron gun and detector now in use have evolved in the last few months as a result of an effort to reduce the background currents to the point where the signal from the metastable atoms is distinctly separated from the photoelectron background.

Using the apparatus described above, we have been able to obtain fairly clean excitation curves for the metastable

state, i.e., curves showing the number of metastable atoms as a function of the energy of the bombarding electrons. An excitation threshold is observed at 54 eV which possesses the correct shape for exchange excitation. A second threshold, this one more complex in its shape and much smaller in magnitude, appears around 62 eV. This may be due to photons from excited states of Li^+, or cascades to the $^4P_{5/2}$ state from a higher, doubly excited state of Li, or both. We are refining the electron gun controls so as to be able to resolve more precisely the various thresholds observed. We are also in the process of making measurements on the neutral lithium beam in order to determine the production cross-section. A determination of the lifetime of the state will be made by measuring the metastable signal as a function of distance from the source, using a movable detector which can be manipulated from outside the vacuum chamber.